

Thunderstorm-mediated Stratospheric Intrusion of Ozone at Surface Sites Along Colorado's Front Range

2015 Western Air Quality Modeling Workshop, 13-15 May
May 13, 2015

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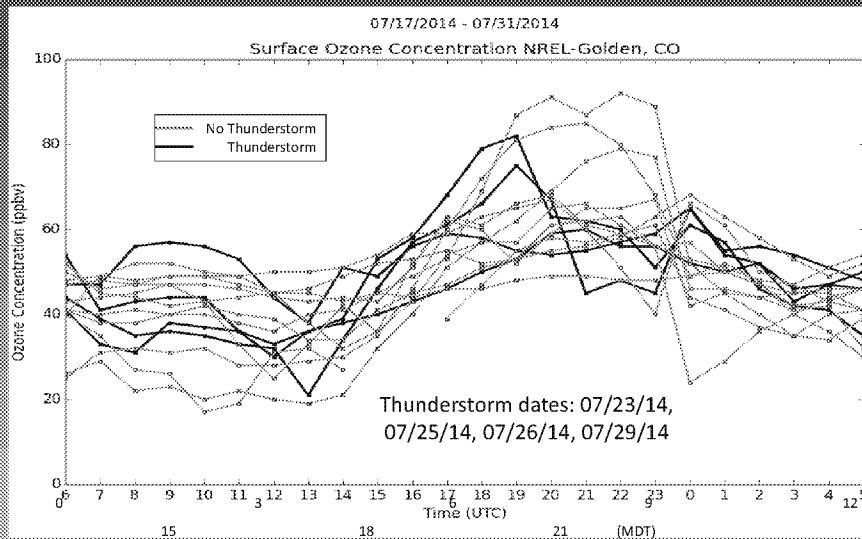
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Patrick J. Reddy CDPHE - do not cite

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Strong Evidence for Thunderstorm-mediated Intrusion May 25, 2014

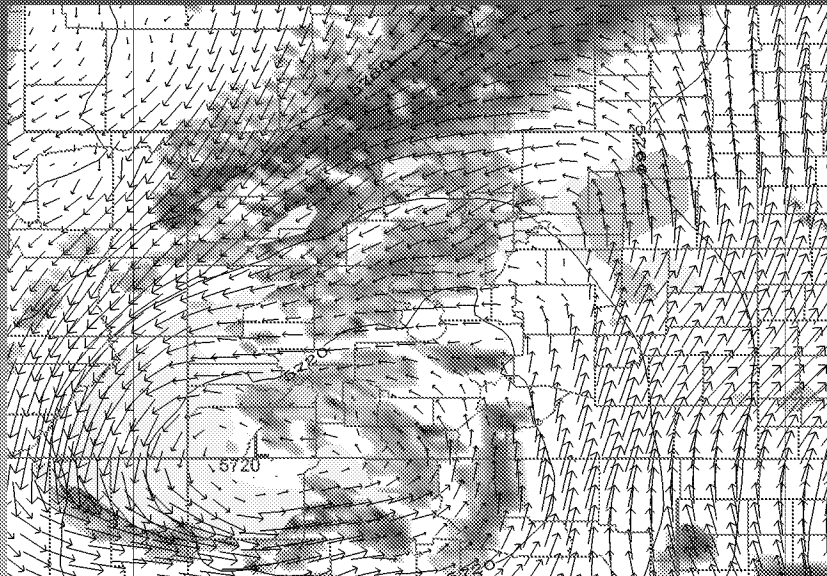
- A closed low with lowered tropopause height and enhanced total column O₃ was over Colorado.
- Cool unsettled conditions near the Front Range with temperatures in the 60s-70s (F) on the plains and snow over the highest terrain.
- A shortwave with a lobe of higher isentropic potential vorticity behind it moved to the northwest across the Front Range.
- The shortwave and deep upslope triggered a line of thunderstorms along the Front Range.
- O₃ increased dramatically near thunderstorms and *in* snow over and near the Divide.
- O₃ increased in storm outflow along the foothills and across the plains in the wake of the storms.
- Models capture the synoptic scale impacts of the intrusion event and show some increases in O₃.
- Decrease in N₂O at NWR suggests intrusion, but “cold lightning” may have been a factor.
- Thunderstorms, a sub-grid scale process, seemed to be a catalyst for an enhanced intrusion event – leading to surface O₃ in excess of model predictions.
- CDPHE forecasters had never witnessed a similar event.



During the Colorado DISCOVER-AQ campaign, thunderstorms routinely reduced surface O₃ at NREL.

Site	May 25, 2014 Max 8-hour O ₃ in ppb
Aspen Park	61
Aurora East	61
South Boulder Creek	62
Chaffield	64
NREL	64
Gothic	61
Greeley	62
La Casa	60
Rocky Flats	67
RMNP	53
Niwot Ridge Tundra	55
BAO Tower 300m	78
ML Evans	85
Kenosha Pass	76
Trout Creek Pass	62

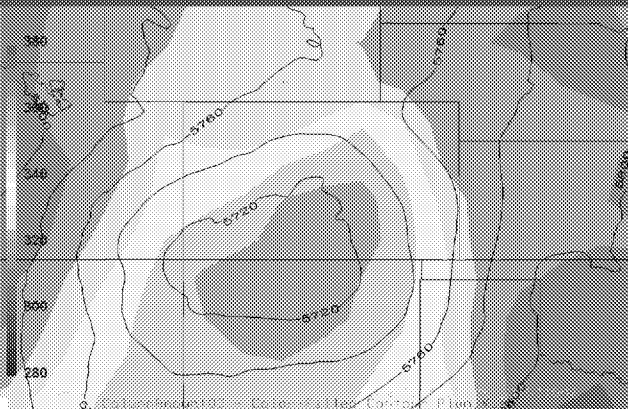
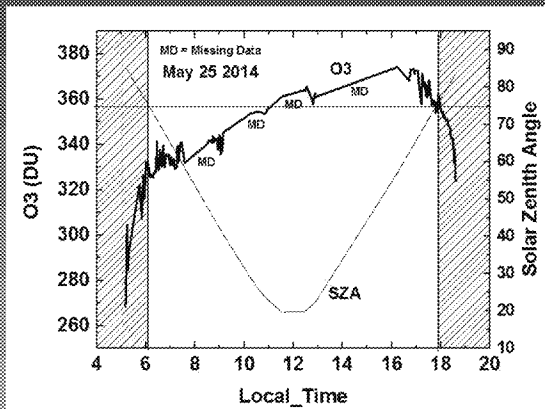
May 25, 2014:
Peak O₃ was in the Moderate to
Unhealthy-for-Sensitive-Groups range.



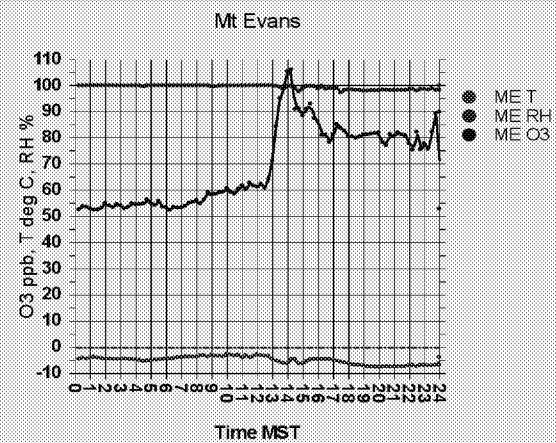
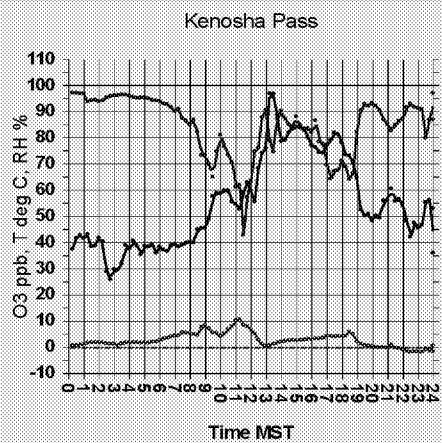
NAM12 18Z Analysis run:

500 mb heights
Closed low southwest Colorado
650 mb winds
650 mb IPV > 1 PVU (yellow)
650 mb RH < 40% (pink)
NAM12 radar blue, green, dark
orange

A lobe of lowered tropopause
behind a shortwave is
moving to the northwest
in northeastern Colorado.



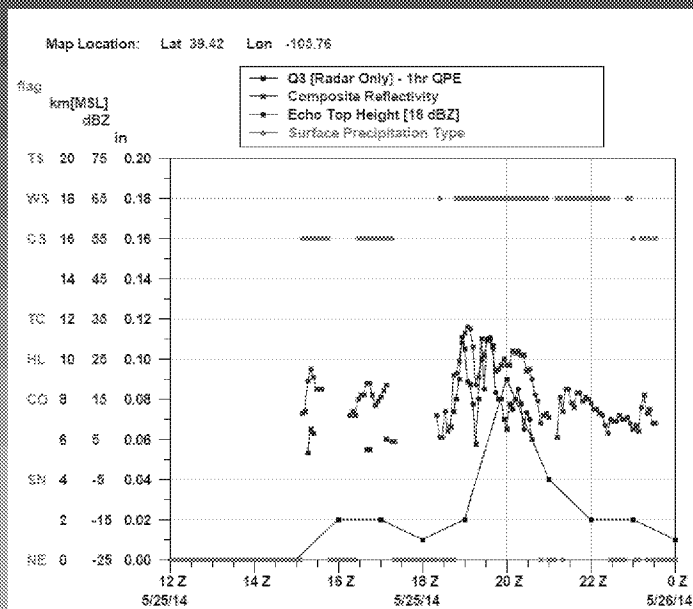
May 25, 2014: NASA Boulder PANDORA total column O3 peaking at 370 DU (left) and OMI total column O3 in DU (right) along with 18Z NAM12 analysis 500 mb heights, showing closed low over southern Colorado, a lobe of higher column O3 over northeast Colorado, and increasing column O3 over Boulder, perhaps in response to shortwave rotating toward the northwest and passing over the Front Range.



USFS 2B Tech 15-minute O3 (ppb), ambient temperature (degrees C), and RH for Kenosha Pass (KP) & Mt Evans (ME). RH and O3 are anti-correlated at KP except from ~11-19 MST. At KP and ME, O3 increases during cooling precipitation event. Snow, or graupel may have fallen.

(CONTINUED)

FOR THE WY 2000-2001, 10/10/01



Point NEXRAD radar analysis For Kenosha Pass:

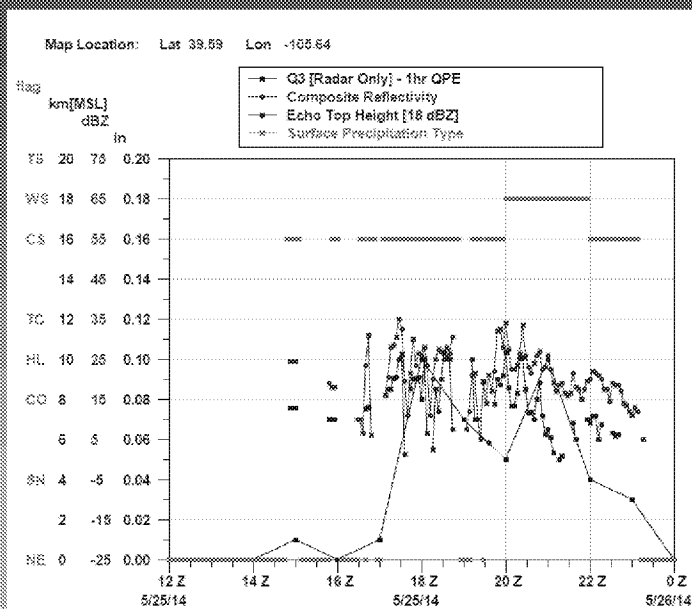
~0.15 inches of precipitation
between 12 and 15 MST.

Echo tops at ~6-12 km.

Reflectivity 3-35 dbz.

Heavy thunderstorm with hail and
0.6 inches precipitation ~18 km
to the east from 13-14 MST.

Source: <http://nmq.ou.edu/>



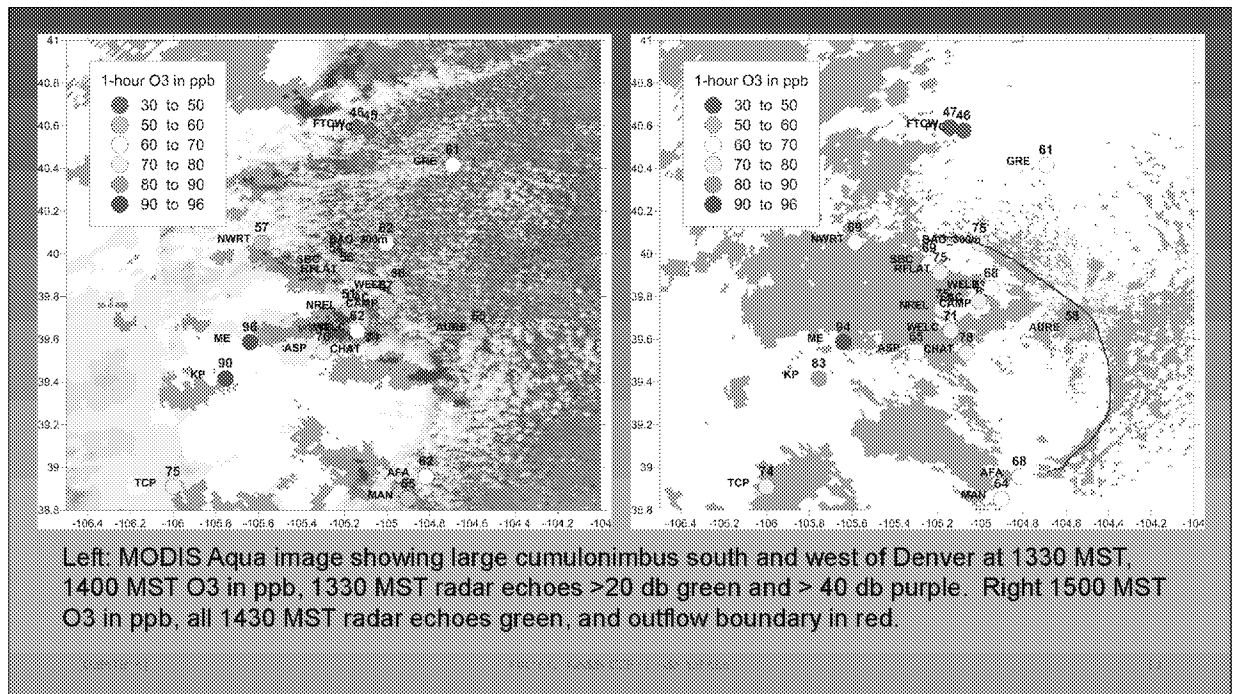
Point NEXRAD radar analysis For Mt Evans:

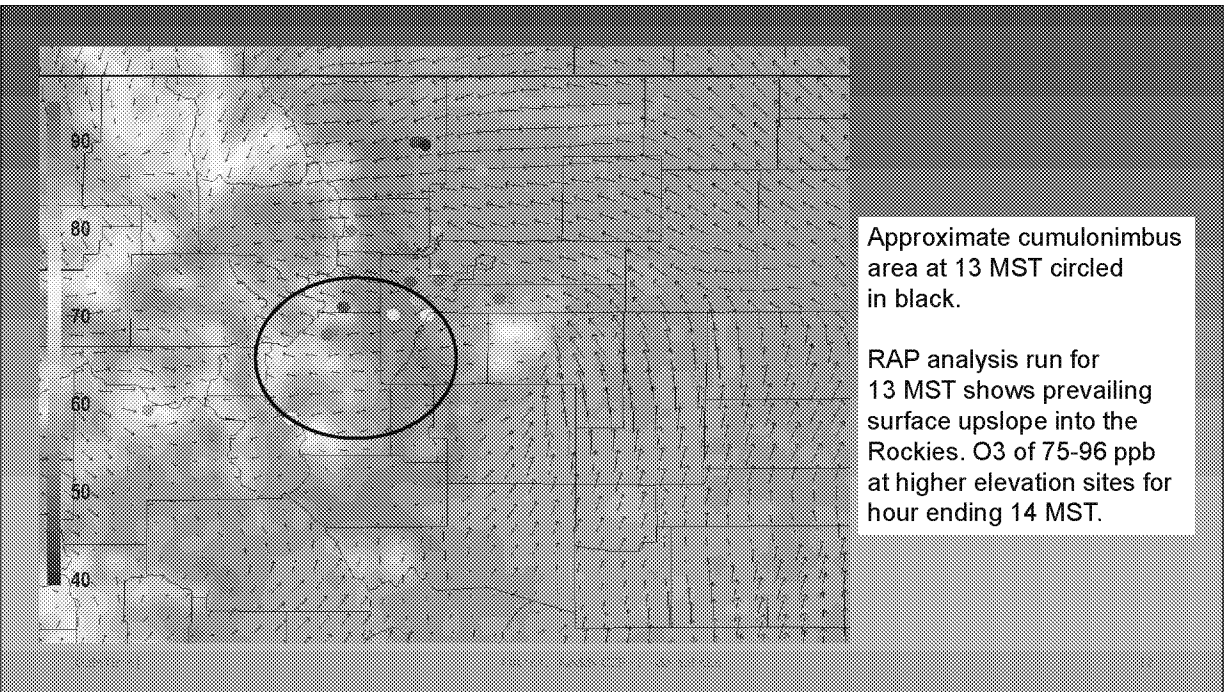
Steady stratiform precipitation
between 6 and 16 MST,
With 0.41 inches.

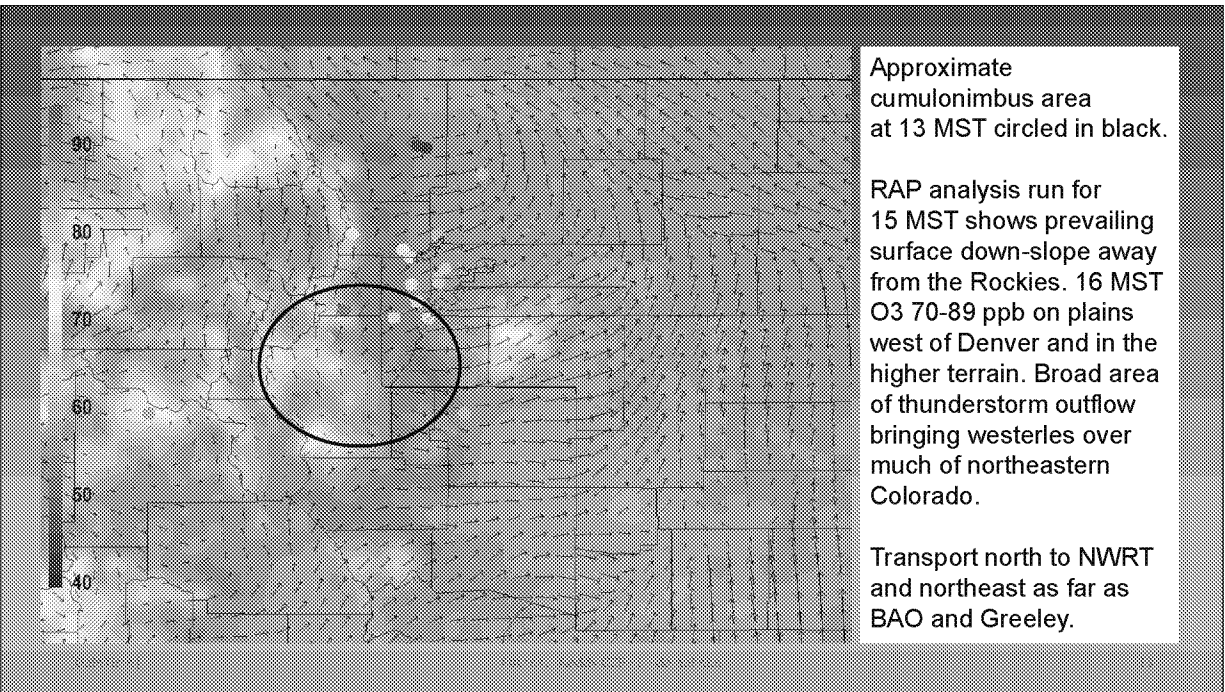
Echo tops generally 6-10 km,
embedded convection?

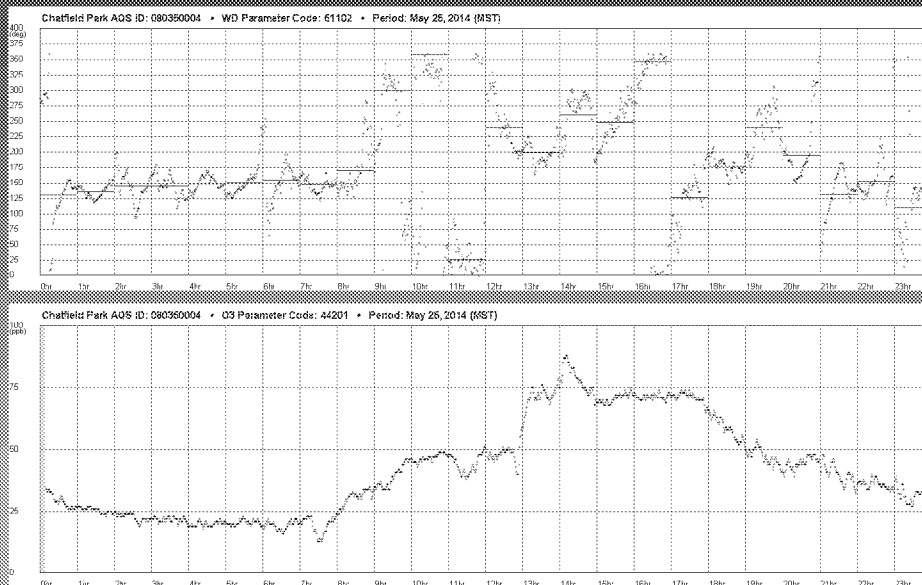
Reflectivity 5-35 dbz.

Source: <http://nmq.ou.edu/>

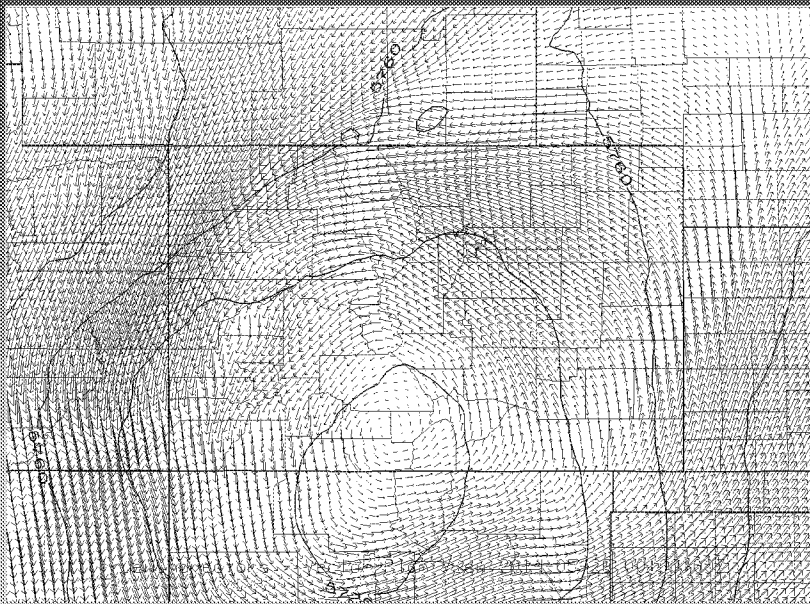






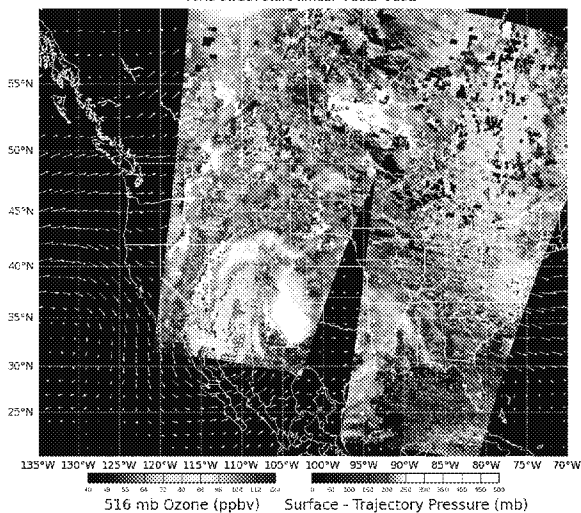


Wind shifts associated with storm gust front usher in > 35 ppb increase in O3 at Chatfield.

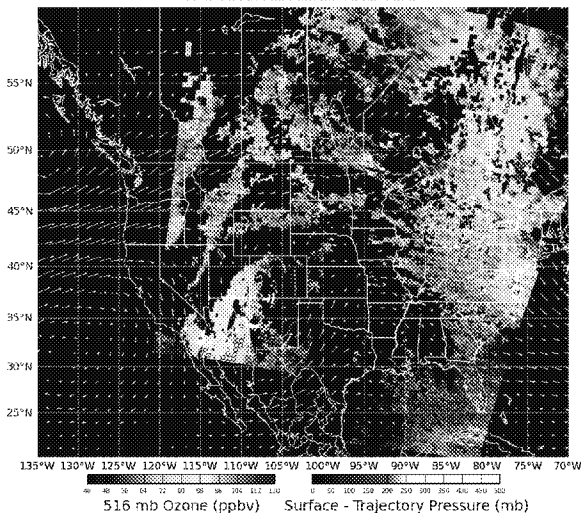


NAM12 analysis run
for 6 PM MST continues
to show deep closed
low and upslope flow
over most of Colorado
at 500 mb.

AIRS Ozone & Ozone Trajectories on 2014-05-24 08Z
AIRS swath start times: 735Z 913Z



AIRS Ozone & Ozone Trajectories on 2014-05-26 00Z
AIRS swath start times: 735Z 913Z

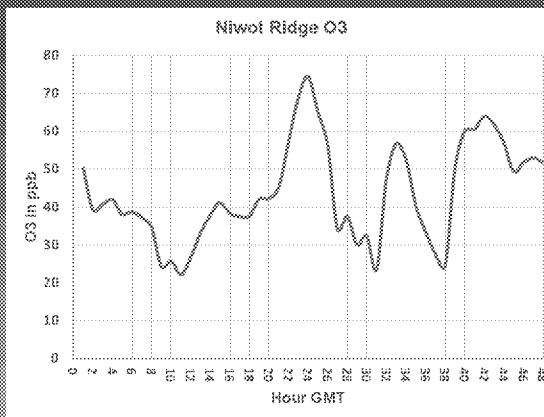
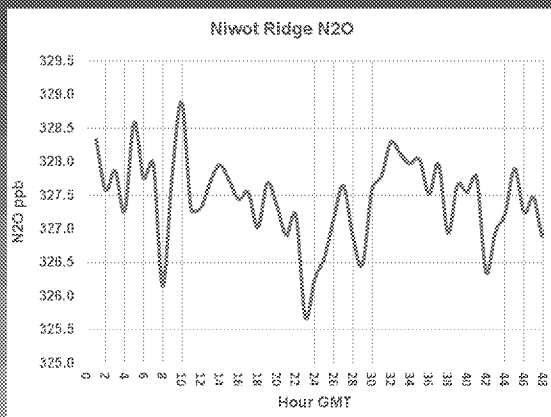


IDEA O3 trajectory forecast tool run on May 24 shows transport from enhanced O3 region at 516 mb in low over AZ to within 250 mb of the surface in Colorado by late in the day on May 25.

05/25/2014

05/25/2014 08:00:00

15



Spike in O3 at Niwot Ridge is coincident with an inverse spike in N2O, suggesting that low-N2O stratospheric air affected the site. Corona discharge (cold lightning) might have contributed to high O3 in the region (A. Kotsakis et al., in preparation, & Minschwaner et al., 2008)

Summary and Conclusions:

- 8-hour O₃ concentrations above the standard with 15-minute values as high as 106 ppb at high altitude sites.
- High concentrations occurred in steady precipitation and thunderstorm outflow.
- High total column O₃, a lobe of higher IPV at mountain-top level and low N₂O support the conclusion that thunderstorms interacted with a streamer of stratospheric air to bring O₃ to the surface.
- How often does this happen? Under a very similar upper low, Mines Peak (Berthoud Pass) saw 1-minute O₃ at 77 ppb in the wake of thundersnow on May 9, 2015. 8-hour O₃ at Gothic peaked at 68 ppb.
- Where tropopause folds mix with moist air in a closed low, neither relative humidity nor IPV may always be good tracers for stratospheric air; diabatic processes in thunderstorms can generate IPV in model analyses.

